(54) **COMBINATION OF N-BUTYLDEOXYNOJIRIMYCIN (NB-DNJ) AND GLYCOLIPID DEGRADING ENZYMES IN THERAPY**

KOMBINATION VON N-BUTYLDEOXYNOJIRIMYCIN (NB-DNJ) UND GLYKOLIPID VERMINDERNDEN ENZYMEN IN THERAPIE

COMBINAISON DE N-BUTYLDEOXYNOJIRIMYCIN (NB-DNJ) ET D'ENZYMES DEGRADANT LES GLYCOLIPIDES UTILISEE EN THERAPIE

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Description

[0001] The present invention relates to the use of a glucosylceramide synthesis inhibitor, N-butyldeoxynojirimycin, in the manufacture of medicaments for use in combination therapy in the treatment of the following disorders which have at least a component based on glycolipid storage: Niemann-Pick C storage disease, Gaucher disease, Sandhoff disease, Tay-Sachs disease, GM1 gangliosidosis and Fabrys disease.

[0002] The GM2 gangliosidoses are a group of glycosphingolipid (GSL) lysosomal storage diseases which includes Tay-Sachs disease, Sandhoff disease and GM2 activator deficiency (Gravel *et al* (1995) in The Metabolic and Molecular Bases of Inherited Disease (Scriver *et al*) Vol 2, pp 2839-79, 3 vols, McGraw Hill, New York). They result from mutations in the genes encoding the hexosaminidase α subunit, β subunit and GM2 activator protein respectively. They are characterised by progressive neurodegeneration in response to high levels of lysosomal storage of GM2 and related GSLs, in neurones of the central nervous system (CNS) (Gravel *et al* (1995) in The Metabolic and Molecular Bases of Inherited Disease (Scriver *et al*) Vol 2, pp 2839-79, 3 vols, McGraw Hill, New York). There are currently no therapies for these diseases. Potential therapeutic strategies for Tay-Sachs and Sandhoff disease include enzyme augmentation and substrate deprivation (Radin (1996) *Glycoconj. J* 13:153-7; Platt *et al* (1998) *Biochemical Pharmacology* 56: 421-30). Augmenting the level of enzyme can be achieved using three clinical strategies, enzyme replacement, bone marrow transplantation or gene therapy.

[0003] Intravenous administration of mannose-terminated glucocerebrosidase (β-D-glycosyl-N-acylsphingosine glucohydrolase, EC 3.2.1.45) is an effective therapy for type 1 Gaucher disease, which is a non-neurological GSL storage disease (Grabowski *et al* (1995) *Ann. Intern. Med.* 122:33-39; Beutler *et al* (1991) *Blood* 78:1183-9). As glycoprotein enzymes fail to cross the blood-brain barrier, this is not a suitable approach for disease involving GSL storage in the CNS. Bone marrow transplantation has the potential to increase enzyme levels in the periphery, and to a limited extent in the CNS due to secretion of enzyme from cells of bone marrow origin, including microglia (Krivit *et al* (1995) *Cell-Transplant* 4:385-392). Results of bone marrow transplantation in GSL lysosomal storage diseases involving storage in the CNS have been mixed (Hoogerbrugge *et al* (1995) *Lancet* 345:1398-1402). Partial success was recently reported in a mouse model of Sandhoff disease given syngeneic wild type bone marrow (Norfus *et al* (1998) *J. Clin. Invest.* 101: 1881-8). This led to increased survival of the mice and improved neurological function. Gene therapy also has promise for treating these diseases, although this is currently experimental (Salvetti *et al* (1995) *Br. Med. Bull* 51: 106-122). Substrate deprivation is a potentially generic pharmacological approach for treating the GSL storage diseases (Platt *et al* (1998) *Biochemical Pharmacology* 56: 421-30), including the GM2 gangliosidoses. This strategy is based upon partial inhibition of the ceramide specific glucosyltransferase (glucosylceramide synthase, UDP-glucose:N-acylsphingosine D-glucosyltransferase, EC 2.4.1.80) which catalyses the first step in GSL biosynthesis (Sandhoff *et al* (1998) *Adv. Lipid Res.* 26:119-142). This would reduce the levels of GSLs synthesised so they could be catabolised fully by the residual enzyme activity present in the cells.

[0004] Substrate deprivation, utilising the GSL biosynthesis inhibitor N-butyldeoxynojirimycin (NB-DNJ), has previously been tested in an *in vitro* model of Gaucher disease and shown to prevent storage (Platt *et al* (1994) *J. Biol. Chem.* 269:8362-6). NB-DNJ has also been evaluated in an asymptomatic mouse model of Tay-Sachs disease and shown to reduce GM2 accumulation in the brain and prevent the neuropathology associated with its storage (Platt *et al* (1997) *Science* 276:428-31).

[0005] The imino sugar N-butyldeoxynojirimycin (NB-DNJ) is a potent inhibitor of alpha-glucosidase 1 (involved in N-glycan synthesis), and an even more potent inhibitor of glucosylceramide glucosyltransferase. NB-DNJ is currently undergoing clinical trials as a treatment for type 1 Gaucher and Fabry diseases, glycolipid storage disorders resulting from mutations in glucocerebrosidase and alpha-galactosidase A, respectively.

[0006] We have now found that NB-DNJ administered to mice together with glucocerebrosidase (the major therapy for Gaucher Type 1 patients) unexpectedly does not compromise the activity of glucocerebrosidase and provides an augmentation of enzyme activity over time due to a protective effect of NB-DNJ on the enzyme. This is surprising as the efficacy of the enzyme would be expected to be compromised in the presence of NB-DNJ as the latter is a weak inhibitor of glucocerebrosidase (IC_{50} = 0.52 mM). Furthermore, we have also found that the co-administration of NB-DNJ with bone marrow transplantation (to provide enzyme augmentation to increase the rate of neuronal glycolipid degradation) provides an unexpected synergistic effect.

[0007] Thus the present invention provides the use of N-butyldeoxynojirimycin (NB-DNJ) in the manufacture of a medicament for administration in combination with an agent capable of increasing the rate of glycolipid degradation in the treatment of a glycolipid storage disorder selected from Gaucher disease, Sandhoffs disease, Fabrys disease, Tay-Sachs disease, Niemann-Pick C storage disease and GM1 gangliosidosis.

[0008] Gaucher disease, Sandhoffs disease, Fabrys disease, Tay-Sachs disease, Niemann-Pick C storage disease and GM1 gangliosidosis are disorders which result from accumulation/storage of glucosylceramide containing glycolipids.

[0009] Agents capable of increasing the rate of glycolipid (preferably but not essentially neuronal glycolipid) degra-

dation include enzymes which degrade glycolipids, e.g. glucocerebrosidase, lysosomal hexoseaminidases, galactos-idases, sialidases and glucosylceramide glucosidase, and molecules which increase the activity of such enzymes. In addition, the agent could comprise a nucleic acid sequence (DNA or RNA) which codes for the enzymes mentioned above, i.e. such sequences could be introduced to increase natural production of such enzymes. The agent may even comprise transplanted bone marrow. A combination of the above agents can be used.

[0010]   The galactose analogue of NB-DNJ, N-butyldeoxygalactonojirimycin (NB-DGJ), is known to inhibit GSL syn-thesis in vitro as effectively as NB-DNJ, but is more specific in that it does not inhibit α-glucosidase I and II or β-glucocerebrosidase (Platt et al, (1994) J Biol Chem 269(43): 27108-14). It is known that only approximately 10% of the serum level of NB-DNJ is present in the cerebrospinal fluid. Accordingly, high systemic doses of NB-DNJ may have to be administered in order to achieve therapeutic levels in the CNS, and may have to be administered for the duration of a patients life. High concentrations of NB-DNJ in humans causes diarrhoea and in mice it causes weight loss and reduces the size of lymphoid organs.

[0011]   It is envisaged that NB-DNJ can be administered to a patient with a glycolipid storage disease in order to maintain low levels of glycolipids. If the dosage of NB-DNJ is incorrect for any reason, an agent for increasing the rate of glycolipid degradation can be administered to restore the low levels of glycolipids.

[0012]   Methods and processes for the production of N-butyldeoxynojirimycin can be found for example in US-A-4182767, EP-B-0012278, EP-A-0624652, US-A-4266025, US-A-4405714 and US-A-5151519.

[0013]   The medicaments described herein may include one or more of the following: preserving agents, solubilising agents, stabilising agents, wetting agents, emulsifiers, sweeteners, colorants, odourants, salts, buffers, coating agents or antioxidants. They may also contain therapeutically active agents in addition to the compounds and/or agents described herein.

Routes of Administration

[0014]   The medicaments may be adapted for administration by any appropriate route, for example by the oral (in-cluding buccal or sublingual), rectal, nasal, topical (including buccal, sublingual or transdermal), vaginal or parenteral (including subcutaneous, intramuscular, intravenous or intradermal) route. Such a composition may be prepared by any method known in the art of pharmacy, for example by admixing the active ingredient with a carrier under sterile conditions.

[0015]   Various routes of administration will now be considered in greater detail:

(i) Oral Administration

[0016]   Medicaments adapted for oral administration may be provided as capsules or tablets; as powders or granules; as solutions, syrups or suspensions (in aqueous or non-aqueous liquids); as edible foams or whips; or as emulsions.

[0017]   Tablets or hard gelatine capsules may comprise lactose, maize starch or derivatives thereof, stearic acid or salts thereof.

[0018]   Soft gelatine capsules may comprise vegetable oils, waxes, fats, semi-solid, or liquid polyols etc.

[0019]   Solutions and syrups may comprise water, polyols and sugars. For the preparation of suspensions oils (e.g. vegetable oils) may be used to provide oil-in-water or water-in-oil suspensions.

(ii) Transdermal Administration

[0020]   Medicaments adapted for transdermal administration may be provided as discrete patches intended to remain in intimate contact with the epidermis of the recipient for a prolonged period of time. For example, the active ingredient may be delivered from the patch by iontophoresis (Iontophoresis is described in Pharmaceutical Research, 3(6):318 (1986)).

(iii) Topical Administration

[0021]   Medicaments adapted for topical administration may be provided as ointments, creams, suspensions, lotions, powders, solutions, pastes, gels, sprays, aerosols or oils.

[0022]   For infections of the eye or other external tissues, for example mouth and skin, a topical ointment or cream is preferably used. When formulated in an ointment, the active ingredient may be employed with either a paraffinic or a water-miscible ointment base. Alternatively, the active ingredient may be formulated in a cream with an oil-in-water base or a water-in-oil base.

[0023]   Medicaments adapted for topical administration to the eye include eye drops. Here the active ingredient can be dissolved or suspended in a suitable carrier, e.g. in an aqueous solvent.

[0024] Medicaments adapted for topical administration in the mouth include lozenges, pastilles and mouthwashes.

(iv) Rectal Administration

[0025] Medicaments adapted for rectal administration may be provided as suppositories or enemas.

(v) Nasal Administration

[0026] Medicaments adapted for nasal administration which use solid carriers include a coarse powder (e.g. having a particle size in the range of 20 to 500 microns). This can be administered in the manner in which snuff is taken, i.e. by rapid inhalation through the nose from a container of powder held close to the nose.
[0027] Compositions adapted for nasal administration which use liquid carriers include nasal sprays or nasal drops. These may comprise aqueous or oil solutions of the active ingredient.
[0028] Medicaments adapted for administration by inhalation include fine particle dusts or mists, which may be generated by means of various types of apparatus, e.g. pressurised aerosols, nebulisers or insufflators. Such apparatus can be constructed so as to provide predetermined dosages of the active ingredient.

(vi) Vaginal Administration

[0029] Medicaments adapted for vaginal administration may be provided as pessaries, tampons, creams, gels, pastes, foams or spray formulations.

(vii) Parenteral Administration

[0030] Medicaments adapted for parenteral administration include aqueous and non-aqueous sterile injectable solutions or suspensions. These may contain antioxidants, buffers, bacteriostats and solutes which render the compositions substantially isotonic with the blood of an intended recipient. Other components which may be present in such compositions include water, alcohols, polyols, glycerine and vegetable oils, for example. Compositions adapted for parenteral administration may be presented in unit-dose or multi-dose containers, for example sealed ampoules and vials, and may be stored in a freeze-dried (lyophilised) condition requiring only the addition of a sterile liquid carrier, e.g. sterile water for injections, immediately prior to use. Extemporaneous injection solutions and suspensions may be prepared from sterile powders, granules and tablets.

Dosages

[0031] Dosages will be readily determinable by routine trials, and will be under the control of the physician or clinician. The guiding principle for determining a suitable dose will be delivery of a suitably efficacious but non-toxic, or acceptably toxic, amount of material. For NB-DNJ, a daily dosage for an adult could be expected to be in the range of from 1 mg to 2 g of active agent, and may be in the range of from 100 to 800 mg or 300 to 600 mg. The dosage may be administered in a single daily dose or alternatively in two, three or more doses during the day.
[0032] Preferred features of each aspect of the invention are as for each of the other aspects *mutatis mutandis*.
[0033] In the accompanying drawings:

Figure 1 is a graph plotting % survival against age of Sandhoff mice in days when treated with different agents.

Figures 2A-D are graphs showing the short term distribution of radiolabelled NB-DNJ and NB-DGJ in mouse. Mice (n = 5 per group) were dissected 90 min after oral administration of [^{14}C]-NB-DNJ (open bars) or [^{3}H]-NB-DGJ (filled bars). A = total compound in intestine and urine. B = total compound in organs. C = compound concentration in serum. D = compound in organs expressed as a ratio to compound in serum. * denotes a significant difference between the NB-DNJ and the NB-DGJ treated mice ($p<0.05$).

Figures 3A-C show glycosphingolipid depletion in mouse liver after feeding NB-DNJ or NB-DGJ. Gangliosides were purified from liver and separated by TLC. GM2 concentration was measured by densitometry of the scanned TLC chromatograms. A = GM2 concentration in livers of mice fed 300 - 4800 mg/kg/day NB-DNJ (open bars) or NB-DGJ (filled bars) for 10 days, (n = 5 per group). B = TLC separated GM2 band of livers from mice treated for 5 weeks with 2400 mg/kg/day. C = densitometry of TLC in B. * denotes significantly lower concentration than the control concentration ($p<0.05$).

Figure 4 shows the growth of mice fed NB-DNJ or NB-DGJ. Mice were given 2400 mg/kg/day of NB-DNJ (o), NB-DGJ (•), or a control diet (□). N = 10 per group. * denotes a significant difference compared to control weights (p<0.01).

Figure 5 shows the lymphoid organ size in mouse after NB-DNJ or NB-DGJ treatment. Wet weight of thymus and spleen was determined at dissection after 5 weeks of treatment with 2400 mg/kg/day of NB-DNJ (open bars). NB-DGJ (filled bars), or a control diet (dashed bars). N = 4 per group. * denotes a significant difference compared to control weights (p<0.001).

Figure 6 shows the inhibition of lactase activity by NB-DNJ, NB-DGJ, DNJ, and DGJ. Lactase activity expressed as % of control activity at different concentrations of NB-DNJ (o), NB-DDJ (•), DNJ (□), and DGJ (■).

[0034]   The invention will now be described with reference to the following examples, which should not in any way be construed as limiting the scope of the invention.

EXAMPLES

Example 1 - Co-administration of Ceredase™ and NB-DNJ

[0035]   A group of mice were treated with NB-DNJ at 4800 mg/kg/day for 5 weeks. After a low intravenous dose (5-10 U/kg) of Ceredase™ (Genzyme Corporation) administered as a single injection via the tail vein, serum enzyme activity was measured by taking sequential serum samples from the tail vein to monitor enzyme activity over time. Ceredase™ is a modified form of β glucocerebrosidase. The results are shown in Table 1 below.

Table 1 -

Effect of NB-DNJ on circulatory activity and half life of Ceredase™		
Mouse	**Peak Activity**	**$T_{1/2}$ (min)**
Control 1	5.8	4.2
2	7.9	3.3
3	8.0	1.5
4	6.8	1.8
5	30.0	1.4
6	2.8	2.0
7	13.6	1.2
8	17.6	1.2
Mean ± sem	11.6 ± 3.1	2.1 ± 0.4
NB-DNJ 1	13.9	1.7
2	32.1	4.9
3	24.1	5.3
4	13.1	3.0
5	21.0	3.5
6	68.3	2.4
7	19.2	2.8
Mean ± sem	27.4 ±7.2	3.4 ± 0.5

[0036]   Ceredase™ activity and serum half lives appeared to be increased in mice treated with NB-DNJ, suggesting a protective effect of the compound to enzyme clearance. Therefore, (a) co-administration of NB-DNJ with Ceredase™ does not compromise activity and (b) there is a surprising augmentation of enzyme activity over time due to a protective

effect of the compound on the enzyme.

Example 2 - Co-administration of NB-DNJ and Bone marrow transplantation in a mouse model of Sandhoff disease

[0037] Sandhoff mice were bone marrow transplanted at two weeks of age and drug therapy initiated at 9.5-11 weeks of age (600 mg/kg/day). Survival curves were plotted for each group of animals with each point on the graph representing a death (see Figure 1). The untreated (no BMT, no drug) survived (longest survivor) until 140 days (filled circles), NB-DNJ only (no BMT) survived until 170 days, BMT only (no NB-DNJ) survived until 200 days, and NB-DNJ plus BMT had extended survival from 200-280 days. The data show synergy approximately 13% above additive.

[0038] In Examples 3-7 below, the following materials and methods were used:

Animals

[0039] Female C57BL/6 mice were housed under standard non-sterile conditions. The mice were provided with water *ad libitum* and prior to drug administration were fed pelleted chow (expended Rat and Mouse Chow 1, SDS Ltd., Witham, Essex, UK). All experiments were performed on age-matched animals.

Treatment of Mice with NB-DNJ and NB-DGJ

[0040] The mice (6 weeks old) were fed a diet of powdered chow (expended Rat and Mouse Chow 3, ground, SDS Ltd.) or diet containing NB-DNJ or NB-DGJ. The diet and compound (both as dry solids) were mixed thoroughly, stored at room temperature, and used within 7 days of mixing. The mice were maintained on NB-DNJ or NB-DGJ at doses of 300 - 4800 mg/kg/day for 10 days, or 2400 mg/kg/day for 5 weeks.

Radiolabelling of NB-DGJ

[0041] A galactose oxidase/Na[^{3}H]$_4$B method was used to radiolabel the C6-carbon of NB-DGJ. A solution of NB-DGJ (1.3 mg), galactose oxidase (80 units), and catalase (37000 units) in 200 µl 10 mM sodium phosphate buffer was incubated for 24h at room temperature whilst stirring. The reaction was stopped by heating the solution to 95°C for 5 min. After centrifuging (10 mins, 13000 rpm), 1M NaOH was added to the supernatant until pH 10-12 was achieved. Na[^{3}H]$_4$B (4.3 mCi) was added and the solution incubated for 2h at 30°C, after which NaBD$_4$ (1 mg) was added and the solution incubated for 1h at 30°C. The solution was neutralised with 1M acetic acid and then dried down. After removing borate by washing with acidified methanol (0.6% glacial acetic acid in methanol) 5-10 times, the [^{3}H]-NB-DGJ mixture was resuspended in water, added to an AG50-column (equilibrated with water) and eluted with 1-4 M NH$_3$. [^{3}H]-NB-DGJ was further purified on HPLC (Dionex CS10 hpcec chromatography, isocratic elution with 50 mM Na$_2$SO$_4$, 2.5 mM H$_2$SO$_4$, 2.5 mM H$_2$SO$_4$, and 5% ACN), and finally the AG50-column step was repeated.

Short-term Distribution of [^{14}C]-NB-DNJ and [^{3}H]-NB-DGJ in Mice

[0042] Mice were orally gavaged with 100 µl water containing 25µg (10^6 cpm) [^{14}C]-NB-DNJ or [^{3}H]-NB-DGJ and 1 mg non-radiolabelled NB-DNJ or NB-DGJ, respectively. Urine and faeces were collected over 90 min. After 90 min the mice were killed and the serum, organs, and any additional urine and faeces were collected. Organs were homogenized in a four fold volume of water and faeces in a ten fold volume. Aliquots of 500 µl homogenate, 100 µl urine, or 50 µl serum were mixed with 4 ml scintillation fluid and [^{14}C] or [^{3}H] counts measured. The quenching by the different tissues of both isotopes was determined by measuring the counts of known amounts of radiolabelled compound added to tissue homogenates, and the results were corrected accordingly.

Glycosphingolipid Analysis of Mouse Liver

[0043] Liver samples were homogenised in water and lyophilised. Dried homogenates were extracted twice in chloroform: methanol (2:1, v/v), first overnight at 4°C and then for 3h at room temperature, pooled and dried under nitrogen. The extracts were resuspended in 500 µl chloroform: methanol (1:1, v/v), base-treated by adding 83 µl of 0.35 M NaOH in methanol and digested for 90 min at room temperature and partitioned by adding 83 µl water: methanol (9:1, v/v), 166.5 µl water and 416 µl chloroform. The upper phase containing the gangliosides was separated from the lower phase after mixing and low speed centrifugation, and the lower phase was washed twice with Folsh (chloroform: methanol: 0.47% KCl, 3:48:47, v/v). Upper phases were combined, dried down to half volume under nitrogen, dialysed against water, lyophilised and resuspended in chloroform: methanol (2:1, v/v). An equivalent of 5 mg dry weight of tissue was separated by TLC chloroform: methanol: 0.22% CaCl$_2$, 60:35:8, v/v). The TLC plate was air-dried, sprayed

with orcinol: sulphuric acid (0.2% (w/v): 2N), and heat-treated (90°C for 10 min). The intensity of bands was quantified by scanning densitometry.

Determination of NB-DNJ and NB-DGJ Concentrations in Serum and Liver

[0044] Serum and supernatant of liver homogenate (130 mg/ml in 10% methanol) were centrifuged three times through a Millipore Ultrafree filter, after an internal standard (NB-pentylDNJ) had been added to the samples. The pooled filtrates were purified on an HC1 preconditioned SCX column, eluted with 1% NH_3 in MeOH, dried down, re-suspended in water, further purified on a C18 column (MeOH preconditioning, H_2O wash, and MeOH elution), and finally quantified by HPLC (Dionex CS10 hpcec chromatography, isocratic elution with 50 mM Na_3SO_4, 2.5 mM H_3SO_4, and 5% ACN).

Purification of Disaccharidases and Measurement of Sucrase, Maltase and Lactase Activity.

[0045] The enzymes sucrase-isomaltase (EC 3.2.1.10/48) and lactase-phlorizin hydrolase (EC 3.2.1.62/108) were purified from porcine intestine at 4°C as follows. The intestine (100g) was cut into small pieces, washed by stirring in 250 ml of 150 mM NaCl/10 mM KCl for 30 min, and extracted twice with 125 ml of 2M urea, 50 mM EDTA, and 50 mM KCl at pH 7. The urea extracts were combined and homogenised (Waring blender), the homogenate was centrifuged at 60,000g for 75 min, and the pellet was resuspended in 50 ml of a solution containing 10 mM EDTA and 10mM L-cysteine-HCl in 50 mM potassium phosphate buffer at pH 7.5 (pre-equilibrated to 37°C). After addition of papain (15 units/ml), the mixture was incubated for 30 min at 37°C, and centrifuged at 105000g for 60 min. The supernatant was removed and precipitated in 75 ml of ethanol at -20°C for 1h. The precipitate was recovered by centrifugation at 5000g for 10 min, dissolved in 5-10 ml of 10 mM potassium phosphate buffer at pH 7.5, and the solution was centrifuged at 30000g for 60 min. The supernatant was removed and stored at 4°C in the presence of 0.02% sodium azide. Sucrase, maltase and lactase activity were determined in the enzyme preparation (diluted to a suitable concentration) by incu-bating 50 μl enzyme. 125 μl sodium citrate buffer (60 mM, pH 6), and 125 μl disaccharide substrate at 37°C for 30 min, heating to 100°C for 3 min to inactivate the enzyme centrifuging the mixture at 13000g for 10 min, and determining the glucose concentration by adding 50 μl of the supernatant to 1 ml trinder reagent (Sigma) and reading the absorbance at 505 nm after 18 min.

Statistical Analysis

[0046] Conventional statistical methods were employed to calculate mean values and standard errors of the mean (S.E.M.). Differences between groups of mice were tested for significance using Student's t-test for unpaired obser-vations. Results in the text and tables are presented as means ± S.E.M.

Example 3 - Short-term Distribution of [³H]-NB-DGJ and [¹⁴C]-NB-DNJ in Mice

[0047] The short-term distribution of NB-DGJ and NB-DNJ in mice was determined by giving the compounds to mice by oral gavage. The radioactive counts in organs, serum, faeces and urine were measured after 90 min. The concen-tration of NB-DNJ was 28% higher than that of NB-DGJ in the total urine collected while in the intestine there was 77% more NB-DGJ than NB-DNJ (Fig. 2A). This suggests that NB-DGJ passed more slowly out of the gastrointestinal (GI) tract relative to NB-DNJ. There appeared to be no difference in distribution of the two compounds in other tissue (Fig. 2B). The serum concentration however differed significantly with a lower level of NB-DGJ relative to NB-DNJ (Fig. 2C), possibly reflecting the slower uptake of NB-DGJ from the GI tract. When adjusted for differential serum levels NB-DGJ was distributed to the tissue more efficiently than NB-DNJ (Fig. 2D).

Example 4 - Long Term Distribution of NB-DGJ and NB-DNJ in Mouse Serum and Liver

[0048] To assay the steady state levels of the compounds when administered long term via the oral route, the con-centrations of NB-DGJ and NB-DNJ in serum and liver were determined by HPLC after treating mice with 2400 mg/kg/day of NB-DNJ or NB-DGJ (non-radiolabelled) for 5 weeks (see Table 2 below). Both serum and liver concentration of drug were higher in NB-DGJ treated mice compared to NB-DNJ treated (66 ± 3.1 μM compared to 51 ± 13.3 μM for serum, and 207 ± 30.6 μM compared to 103 ± 21.2 for liver). The level of NB-DGJ in liver compared to that of NB-DNJ suggests that NB-DGJ is selectively taken up into the liver as compared to NB-DNJ. Thus, NB-DGJ may enter tissues more efficiently and persist longer than NB-DNJ.

Table 2 -

Concentration of NB-DGJ and NB-DNJ in serum and liver: Mice were treated with 2400 mg/kg/day of NB-DGJ or NB-DNJ for 5 weeks (n=2), and the compound concentration in serum and liver was then determined by duplicate runs on HPLC.		
	Compound concentration (µM)	
	Serum	Liver
NB-DGJ	60 ± 3.1	207 ± 30.6
NB-DNJ	51 ± 13.3	103 ± 21.2

Example 5 - Depletion of GSL by NB-DGJ and NB-DNJ

[0049]   The degree of GSL depletion in liver after 10 days or 5 weeks of treatment was compared between mice administered NB-DGJ or NB-DNJ. The livers were chloroform: methanol-extracted, gangliosides were analysed by thin layer chromatography and the GM2 band intensity was quantitated by densitometry. The relative GM2 concentrations (compared to control mice) in livers of mice treated with a range of NB-DGJ or NB-DNJ doses (300-4800 mg/kg/day) for 10 days show a dose-dependent response to both compounds (see Fig. 3A). There was no significant difference between the GM2 depletion achieved by the two compounds at any of the concentrations tested. After longer treatment (2400 mg/kg/day for 5 weeks), the GM2 concentrations in livers of mice treated with NB-DNJ or NB-DGJ were reduced to 35 ± 4% and 26 ± 11%, respectively, in relation to the concentration in control livers (see Figs. 3B and C).

[0050]   Thus, both analogues (NB-DNJ and NB-DGJ) were shown to be potent inhibitors of GSL biosynthesis _in vivo_. After 10 days of treatment, dose-dependent GSL depletion was seen in livers of mice fed either NB-DNJ or NB-DGJ. The lowest dose causing GSL depletion was 600 mg/kg/day (25% reduction). The highest dose evaluated (4800 mg/kg/day) caused 60-70% depletion. Similar data were obtained with both compounds. Although there is a two fold higher concentration of NB-DGJ in liver this was not observed when GSL depletion was measured, where both compounds gave comparable inhibition of GM2 biosynthesis. This may reflect differential cellular uptake of the compounds into hepatocytes, endothelial cells and Kuppfer cells as GM2 may be primarily the product of one cell type whereas the compound could be sequestered in non-GM2 synthesising cells. GSL depletion after longer treatment at a dosage of 2400 mg/kg/day was also determined. After 5 weeks of feeding, the GM2 concentration was reduced by 74% by NB-DGJ and 65% by NB-DNJ.

Example 6 - Effects of NB-DGJ and NB-DNJ on Growth and Lymphoid Organ Size

[0051]   To examine the overall well being of the mice treated with NB-DGJ or NB-DNJ (2400 mg/kg/day for 5 weeks) the mice were monitored 2-3 times per week, body weights recorded, and the effects of NB-DGJ and NB-DNJ on growth rates determined (see Fig. 4). The NB-DNJ treated mice grew more slowly than untreated control mice, while NB-DGJ treated mice showed no difference in growth rates relative to the untreated controls. After 5 weeks of treatment, the NB-DNJ mice weighed 25% less than control and the NB-DGJ mice. Thymuses and spleens removed from NB-DNJ mice were smaller than those of control or NB-DGJ mice (see Fig. 5), while the weights of other organs such as liver and kidney were unaffected. Treatment with NB-DNJ reduced the thymus weight by 61 ± 2% and spleen weight by 62 ± 3% compared to organs from control mice. In contrast, NB-DGJ had no effect on lymphoid organ weight. The loss of body weight in NB-DNJ mice did not account for the large reduction in lymphoid organ size. If expressed as a ratio to body weight, the organ weights were still reduced significantly (thymus to body weight ratio was reduced by 45 ± 5% and spleen to body weight ratio by 48 ± 4% in NB-DNJ mice compared to controls). It was observed that NB-DNJ treated mice had less fat associated with their organs (kidney, spleen etc.) and lacked subcutaneous fat compared to control or NB-DGJ treated mice (data not shown).

[0052]   The fact that loss of body weight and reduction of lymphoid organ size is caused by NB-DNJ but not by NB-DGJ suggests that these effects are a function of glucosidase inhibition (or an as yet unidentified activity) by NB-DNJ, not GSL biosynthesis inhibition (an activity shared by both compounds). The effect of NB-DNJ in the present study on the inhibition of glycogen breakdown could provide a possible explanation for at least part of the weight loss observed in NB-DNJ treated mice. It was shown that, after 12h of starvation, when the control and NB-DGJ treated mice had depleted most of their glycogen, NB-DNJ treated mice still had a significant amount of glycogen in their livers. Both following starvation and between episodes of feeding, the mouse would normally break down glycogen to provide the brain, muscles and other tissues of the body with glucose. However, if glycogenoloysis was partial inhibited, as in the NB-DNJ treated mice, the mouse would have to use other fuel sources, such as fat, to meet its energy demand.

The store of adipose tissue would decrease with time resulting in reduced body weight. This hypothesis fits with the observation that the NB-DNJ treated mice (both fed and starved) had very little subcutaneous fat compared to normal or NB-DGJ treated mice. The inhibition of glycogenolysis by NB-DGJ is probably due to inhibition of the glycogen debranching enzyme (4-α-glucanotransferase, EC 2.4.1.25 and α-1,6-glucosidase, EC 3.2.1.33). Although never reported for NB-DNJ, inhibition of the α-1,6-glucosidase activity of this enzyme has previously been observed for other DNJ-derivatives (Arai et al 1998, *Circulation* 97(13): 1290-7; Bollen et al *Eur-J-Biochem* 181(3): 775-80). If this is also the case for NB-DNJ, over prolonged treatment periods this could cause (pathological) glycogen storage. If this does occur however, it is exceeding slow storage as animals on drug for prolonged periods in excess of six months show no overt signs of pathology (data not shown). What may be occurring is that the basal level of glycogen is increased due to partial enzyme inhibition, but that this remains relatively constant over time at the doses of inhibitor used in this study.

[0053]   NB-DNJ treated mice had consistently smaller lymphoid organs. However, NB-DGJ did not show this effect, again implying that this is not the result of GSL biosynthesis inhibition in animals treated with NB-DNJ.

Example 7 - Inhibition of Disaccharidases in Vitro

[0054]   NB-DGJ, NB-DNJ and the parental non-alkylated compound DNJ were assessed for their capacities to inhibit the sucrase and maltase activities of the enzyme sucrase-isomaltase (which has disaccharidase activities for the breakdown of sucrose, maltose and isomaltose). Inhibition of this enzyme by DNJ has previously been reported (Hanozet et al., (1981), *J. Biol. Chem* 256:3703-3711). Both substrate and inhibitor concentrations were varied and the K_i calculated (see Table 3). NB-DNJ and DNJ were found to be potent inhibitors of both sucrase and maltase (K_i (sucrase) = 0.03 μM and K_i (maltase) = 0.07 μM for DNJ, and K_i (sucrase) = 0.26 μM and K_i (maltase) = 0.37 μM for NB-DNJ), while NB-DGJ was less potent (K_i (sucrase) = 2 mM, (maltase) non-inhibitor at 2 mM).

[0055]   NB-DNJ, DNJ, NB-DGJ and DGJ were also tested for their capacity to inhibit lactase (Fig. 6 and Table 4). DNJ, NB-DGJ and DGJ all inhibited lactase (K_i of 13 μM, 30 μM and 85 μM for DNJ, DGJ and NB-DGJ, respectively). Lactase inhibition by NB-DNJ was very weak (K_i = 4 mM).

Table 3 -

K_is for the inhibition of sucrase and maltase by DNJ, NB-DNJ and NB-DGJ. NI (non-inhibitory at 2mM).		
	$K_i (\mu M)$	
	Sucrase	*Maltase*
DNJ	0.03	0.07
NB-DNJ	0.26	0.37
NB-DGJ	2000	NI

Table 4-

K_is for the inhibition of lactase by DNJ, NB-DNJ, DGJ and NB-DGJ.	
	$K_i (\mu M)$
DNJ	13
NB-DNJ	4000
DGJ	30
NB-DGJ	85

[0056]   The primary side effect of NB-DNJ has been observed to be osmotic diarrhoea. The diarrhoea is thought to be caused by inhibition of disaccharidases in the intestine, which means that sugars like sucrose and maltose cannot be catabolised and absorbed from the digestive system. Sucrose consists of one glucose and one fructose residue, and maltose of two glucose residues. It is therefore not surprising that the results in this example show that the glucose analogues NB-DNJ and DNJ are very potent inhibitors of the sucrase and maltase activity while the galactose analogue NB-DGJ is not inhibitory. It was found that DNJ, NB-DGJ and DGJ all inhibited lactase, but the K_is were at least 10^2 times higher than for sucrase and maltase inhibition by the glucose analogues. NB-DNJ, however, was not a good inhibitor of lactase (K_i 4mM).

Table 5

	NB-DNJ	NB-DGJ
GSL Biosynthesis	+	+
Weight loss	+	-
Lymphoid organ reduction	+	-
ER α-glucosidase I and II inhibition*	+	-
Sucrase and maltase inhibition**	+	-
Lactase inhibition***	-	+

* Platt et al (1994) *J Biol Chem* 269(43): 27108-14

** K_i (sucrase) = 0.26µM, K_i (maltase) = 0.37 µM for NB-DNJ

*** K_i (lactase) = 85 µM for NB-DGJ samples (shown in parentheses).

Claims

1. The use of N-butyldeoxynojirimycin (NB-DNJ) in the manufacture of a medicament for administration in combination with an agent capable of increasing the rate of glycolipid degradation in the treatment of a glycolipid storage disorder selected from Gaucher disease, Sandhoffs disease, Fabrys disease, Tay-Sachs disease, Niemann-Pick C storage disease and GM1 gangliosidosis.

2. The use according to claim 1, wherein the glycolipid storage disorder is Gaucher disease.

3. The use according to claim 1 or 2, wherein the agent capable of increasing the rate of glycolipid degradation is an enzyme involved in glycolipid degradation.

4. The use according to claim 3, wherein the enzyme is selected from the group consisting of glucocerebrosidase, lysosomal hexoseaminidase, galactosidase, sialidase, and glucosylceramide glucosidase.

5. The use according to claim 4, wherein the enzyme is a glucocerebrosidase.

6. The use according to claim 1 or 2, wherein the agent capable of increasing the rate of glycolipid degradation is a molecule which increases the activity of a glycolipid degrading enzyme.

7. The use according to claim 1 or 2, wherein the agent capable of increasing the rate of glycolipid degradation is a nucleic acid sequence which encodes a glycolipid degrading enzyme.

8. The use according to claim 1 or 2, wherein the agent capable of increasing the rate of glycolipid degradation is transplanted bone marrow.

9. The use according to any one of claims 1 to 8, wherein the medicament is adapted for simultaneous, sequential, or separate administration with the agent capable of increasing the rate of glycolipid degradation.

10. The use according to any one of claims 1 to 9, wherein the medicament is adapted for oral administration.

Patentansprüche

1. Verwendung von N-Butyldesoxynojirimycin (NB-DNJ) für die Herstellung eines Arzneimittels zur Verabreichung in Kombination mit einem Wirkstoff, der zur Steigerung der Rate des Glycolipid-Abbaus geeignet ist, zur Behandlung einer Glycolipid-Speicherkrankheit ausgewählt aus Gaucher-Syndrom, Sandhoff-Syndrom, Fabry-Syndrom, Tay-Sachs-Syndrom, Niemann-Pick C-Speicherkrankheit und GM1-Gangliosidose.

2. Verwendung nach Anspruch 1, wobei die Glycolipid-Speicherkrankheit das Gaucher-Syndrom ist.

3. Verwendung nach einem der Ansprüche 1 oder 2, wobei der Wirkstoff, der zur Steigerung der Rate des Glycolipid-

Abbaus geeignet ist, ein Enzym ist, welches am Glycolipid-Abbau beteiligt ist.

4. Verwendung nach Anspruch 3, wobei das Enzym ausgewählt ist aus der Gruppe bestehend aus Glucocerebrosi-
    dase, lyosomaler Hexoseaminidase, Galactosidase, Sialidase und Glucosylceramid-Glucosidase.

5. Verwendung nach Anspruch 4, wobei das Enzym Glucocerebrosidase ist.

6. Verwendung nach Anspruch 1 oder 2, wobei der Wirkstoff, der zur Steigerung der Rate des Glycolipid-Abbaus
    geeignet ist, ein Molekül ist, welches die Aktivität eines Glycolipid-abbauenden Enzyms steigert.

7. Verwendung nach Anspruch 1 oder 2, wobei der Wirkstoff, der zur Steigerung der Rate des Glycolipid-Abbaus
    geeignet ist, eine Nucleinsäuresequenz ist, die ein Glycolipid-abbauendes Enzym codiert.

8. Verwendung nach Anspruch 1 oder 2, wobei der Wirkstoff, der zur Steigerung der Rate des Glycolipid-Abbaus
    geeignet ist, transplantiertes Knochenmark ist.

9. Verwendung nach einem der Ansprüche 1 bis 8, wobei das Arzneimittel angepasst ist für eine gleichzeitige, auf-
    einanderfolgende oder separate Verabreichung mit dem Wirkstoff, der zur Steigerung der Rate des Glycolipid-
    Abbaus geeignet ist.

10. Verwendung nach einem der Ansprüche 1 bis 9, wobei das Medikament für eine orale Verabreichung angepasst ist.

Revendications

1. L'utilisation de la N-butyldésoxynojirimycine (NB-DNJ) dans la fabrication d'un médicament pour l'administration
    en combinaison avec un agent pouvant augmenter la vitesse de dégradation de glycolipides lors du traitement
    d'un trouble du stockage de glycolipides choisi parmi les maladie de Gaucher, maladie de Sandhoff, maladie de
    Fabrys, maladie de Tay-Sachs, maladie du stockage C de Niemann-Pick et gangliosidose GM1.

2. L'utilisation selon la revendication 1, dans laquelle le trouble du stockage de glycolipides est la maladie de Gaucher.

3. L'utilisation selon l'une quelconque des revendications 1 ou 2, dans laquelle l'agent pouvant augmenter la vitesse
    de dégradation de glycolipides est une enzyme impliquée dans la dégradation des glycolipides.

4. L'utilisation selon la revendication 3, dans laquelle l'enzyme est choisie dans le groupe consistant en glucocéré-
    brosidase, hexoséaminidase lysosomale, galactosidase, sialidase et glucosylcéramide glucosidase.

5. L'utilisation selon la revendication 4, dans laquelle l'enzyme est une glucocérébrosidase.

6. L'utilisation selon l'une quelconque des revendications 1 ou 2, dans laquelle l'agent pouvant augmenter la vitesse
    de la dégradation des glycolipides est une molécule qui augmente l'activité d'une enzyme dégradant les glycoli-
    pides.

7. L'utilisation selon l'une quelconque des revendications 1 ou 2, dans laquelle l'agent pouvant augmenter la vitesse
    de dégradation des glycolipides est une séquence d'acide nucléique qui code pour une enzyme dégradant les
    glycolipides.

8. L'utilisation selon l'une quelconque des revendications 1 ou 2, dans laquelle l'agent pouvant augmenter la vitesse
    de la dégradation des glycolipides est de la moelle osseuse transplantée.

9. L'utilisation selon l'une quelconque des revendications 1 à 8, dans laquelle le médicament est mis au point pour
    une administration simultanée, séquentielle ou séparée avec l'agent pouvant augmenter la vitesse de la dégra-
    dation des glycolipides.

10. L'utilisation selon l'une quelconque des revendications 1 à 9, dans laquelle le médicament est mis au point pour
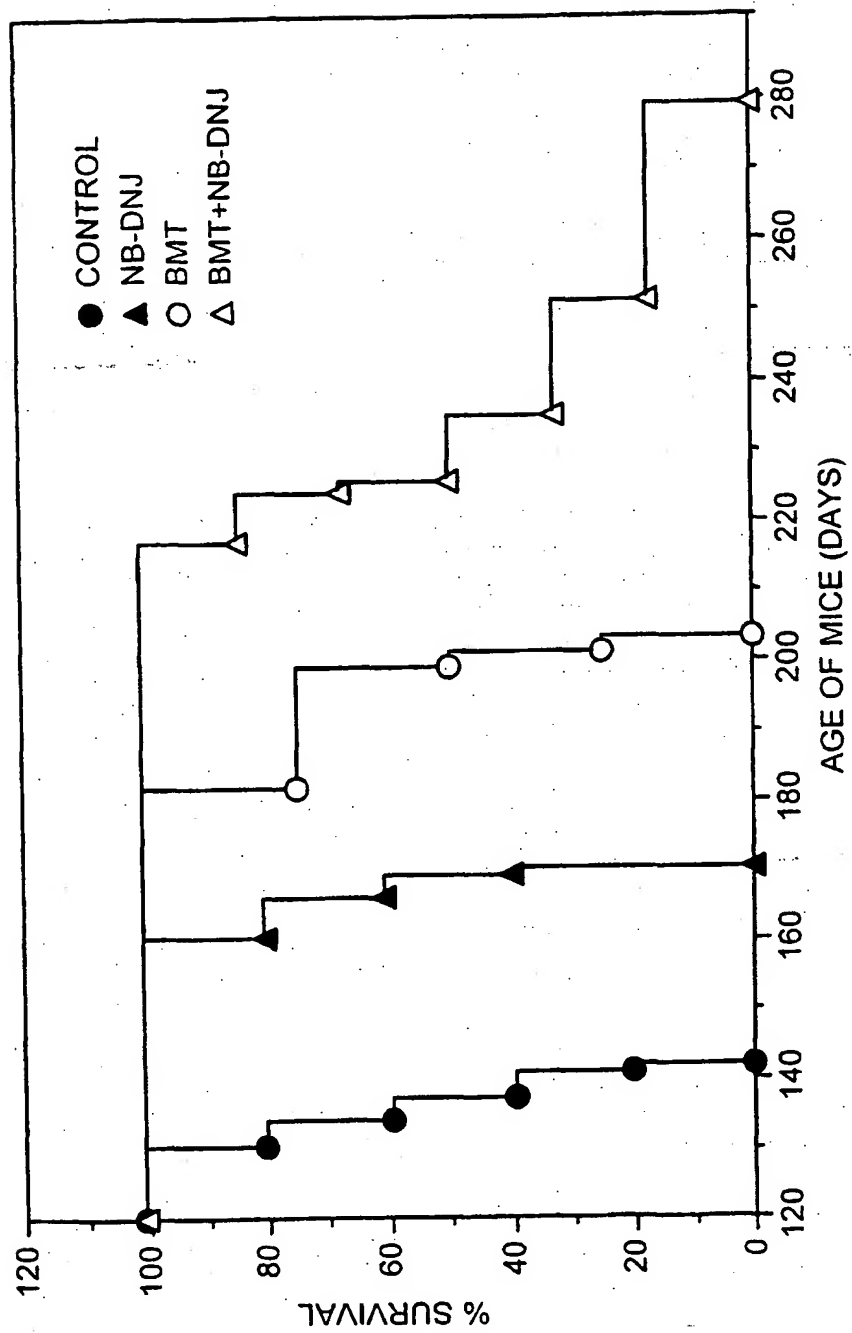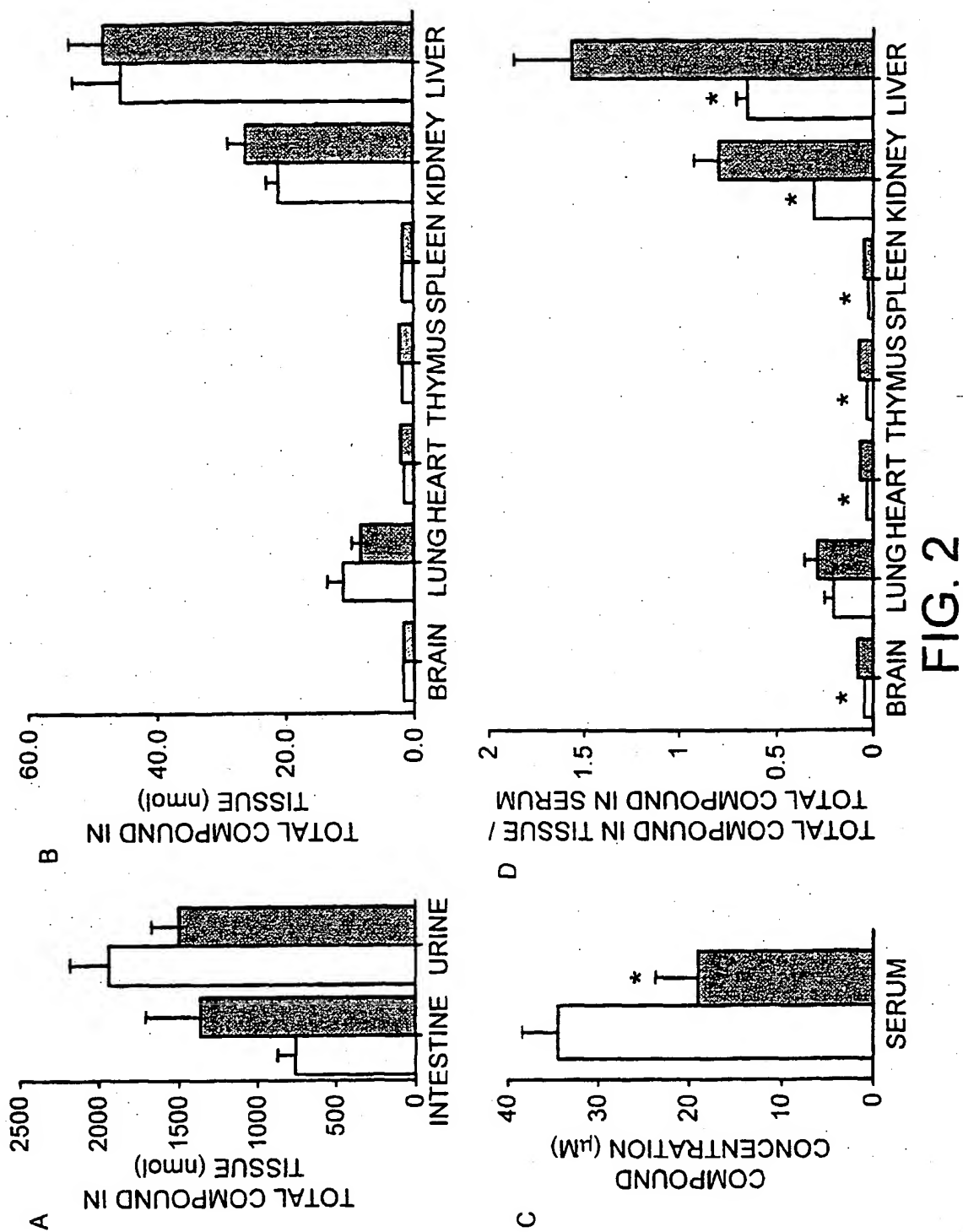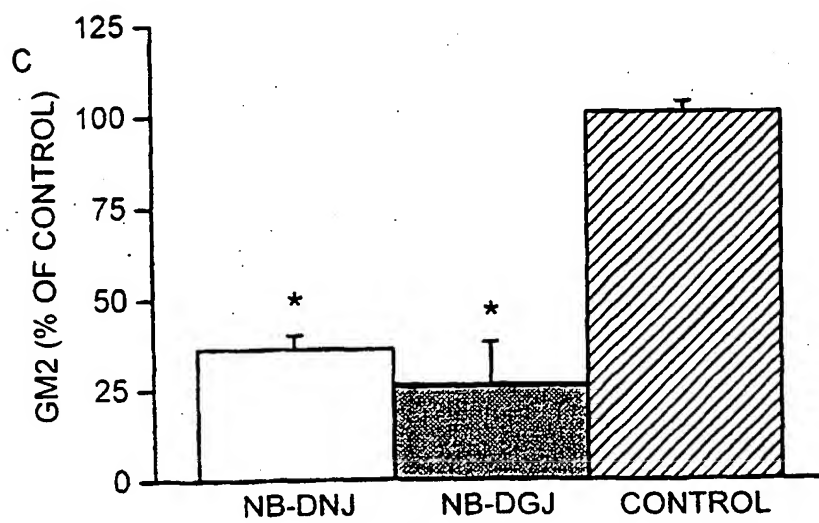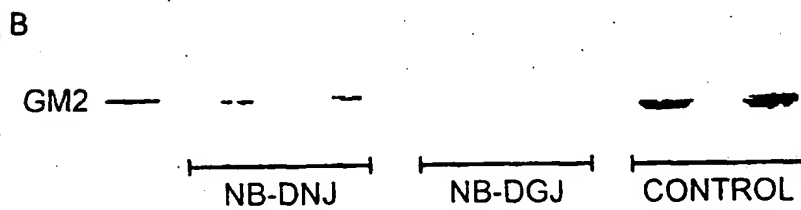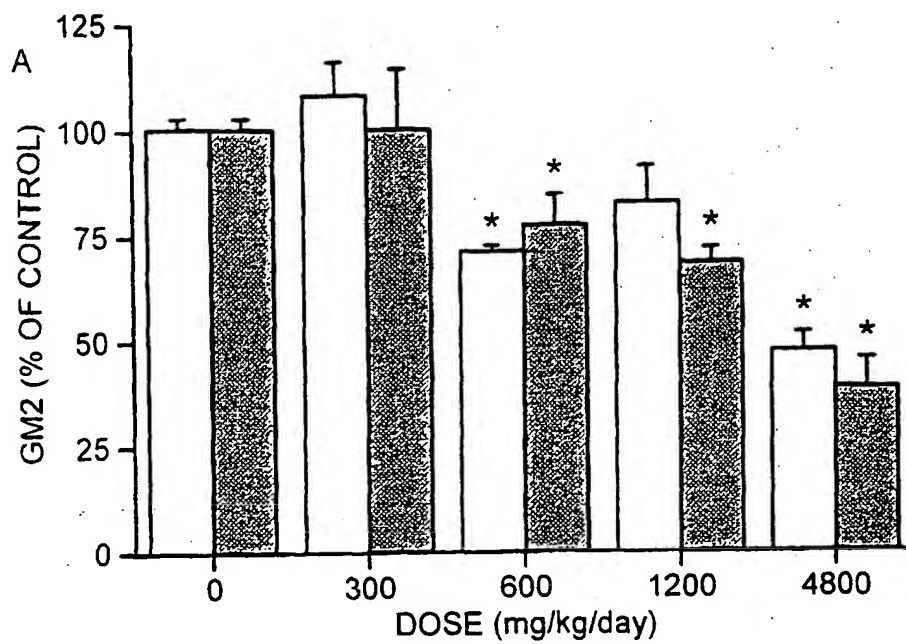   l'administration orale.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6